Beam-Beam Compensation in the Tevatron and LHC

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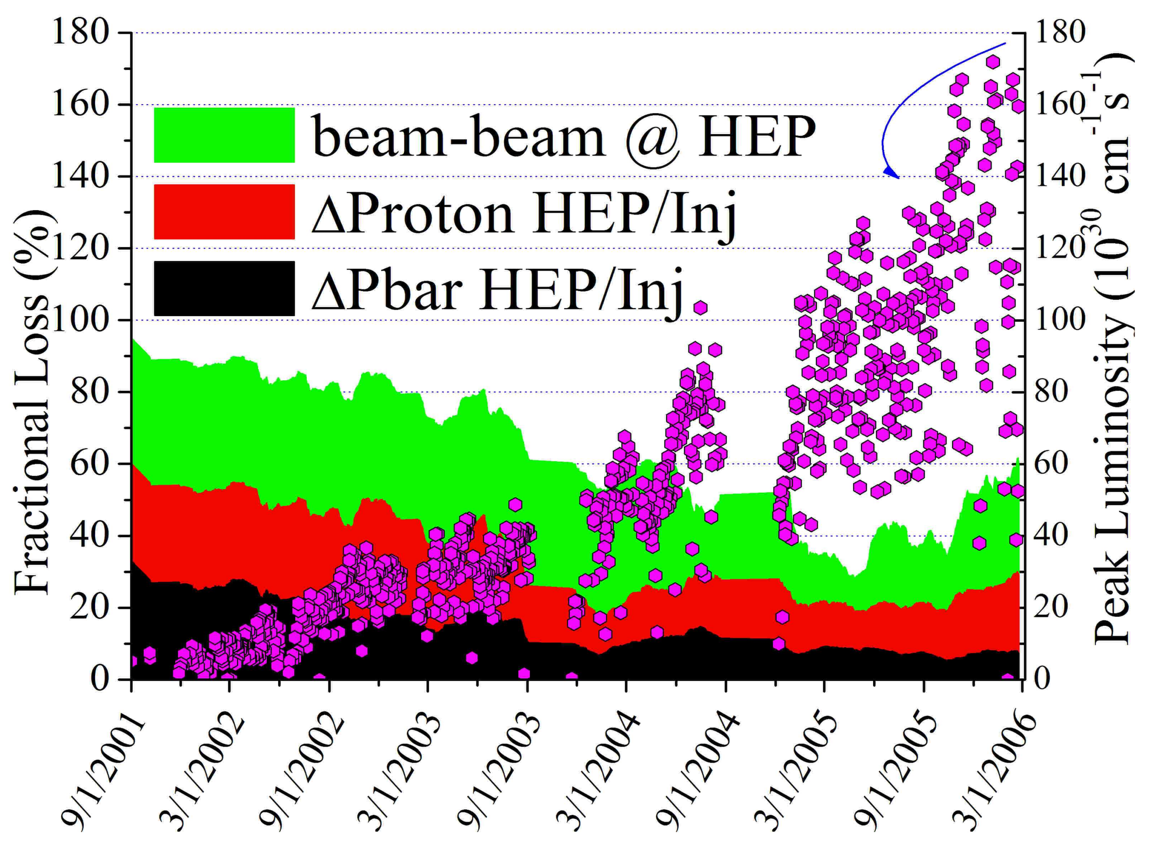
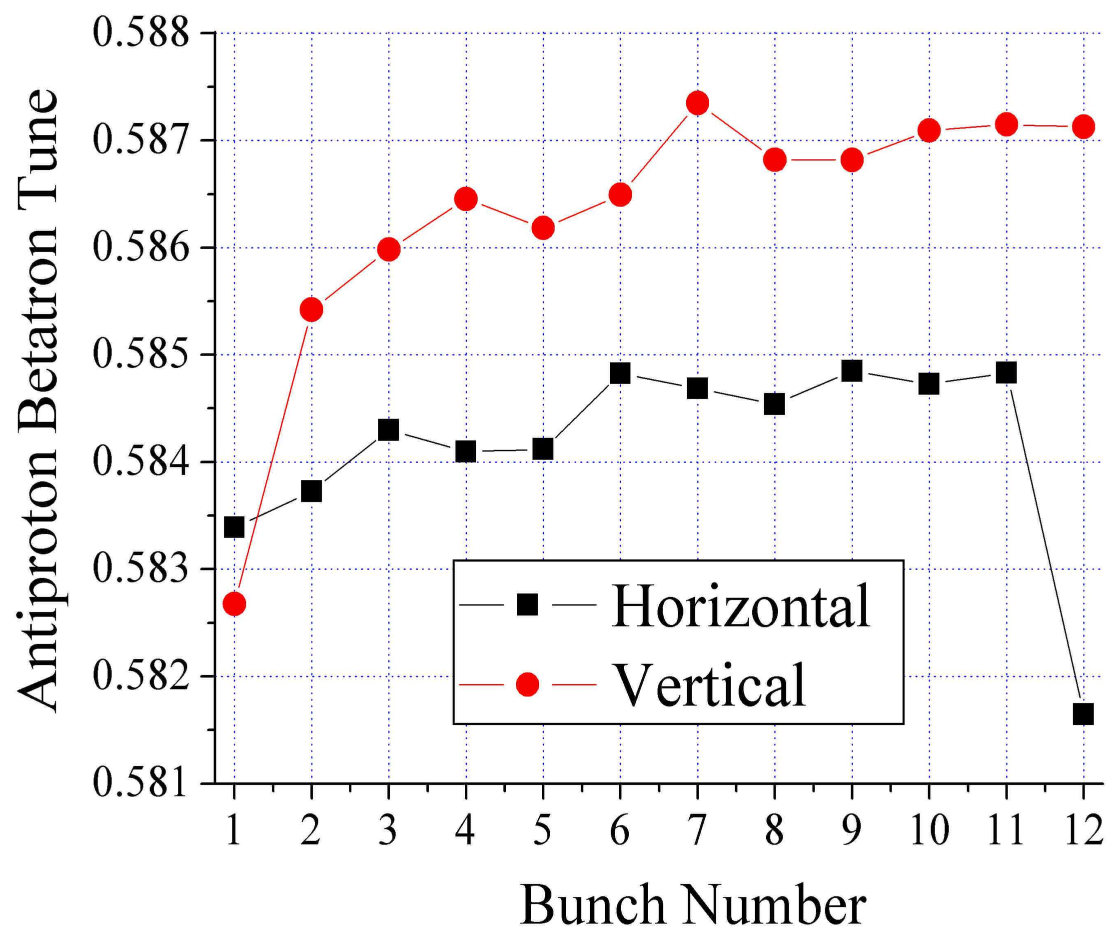
Introduction

Beam losses and peak luminosity in the Tevatron



Effects associated with both head on and parasitic beam-beam interaction have been observed in the Tevatron.

Bunch-by-bunch tune spread as a result of parasitic beam-beam interaction



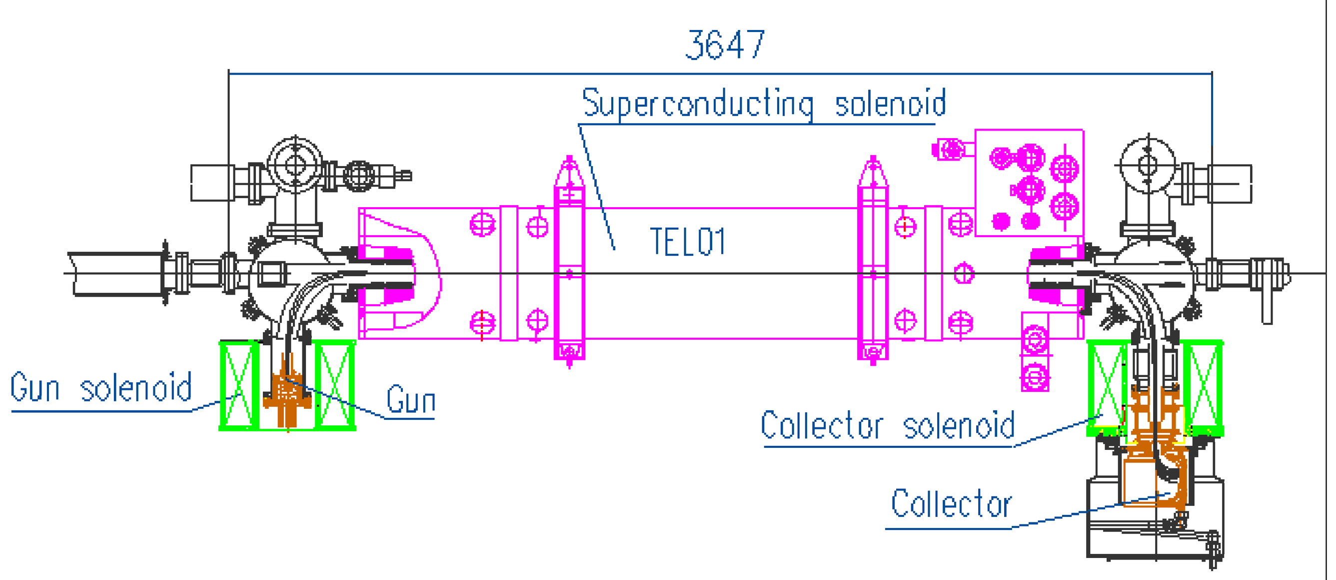
The goal of linear Beam-Beam Compensation (BBComp) is to reduce beam losses by reducing bunch-by-bunch tune spread. Bunches circulating in the machine have to be treated individually.

A device called Tevatron Electron Lens (TEL) has been designed and installed in 2001. Pulsed electron beam is placed on pbar/proton orbit. A number of beam studies showed tune shifts up to 0.009.

Project status, results

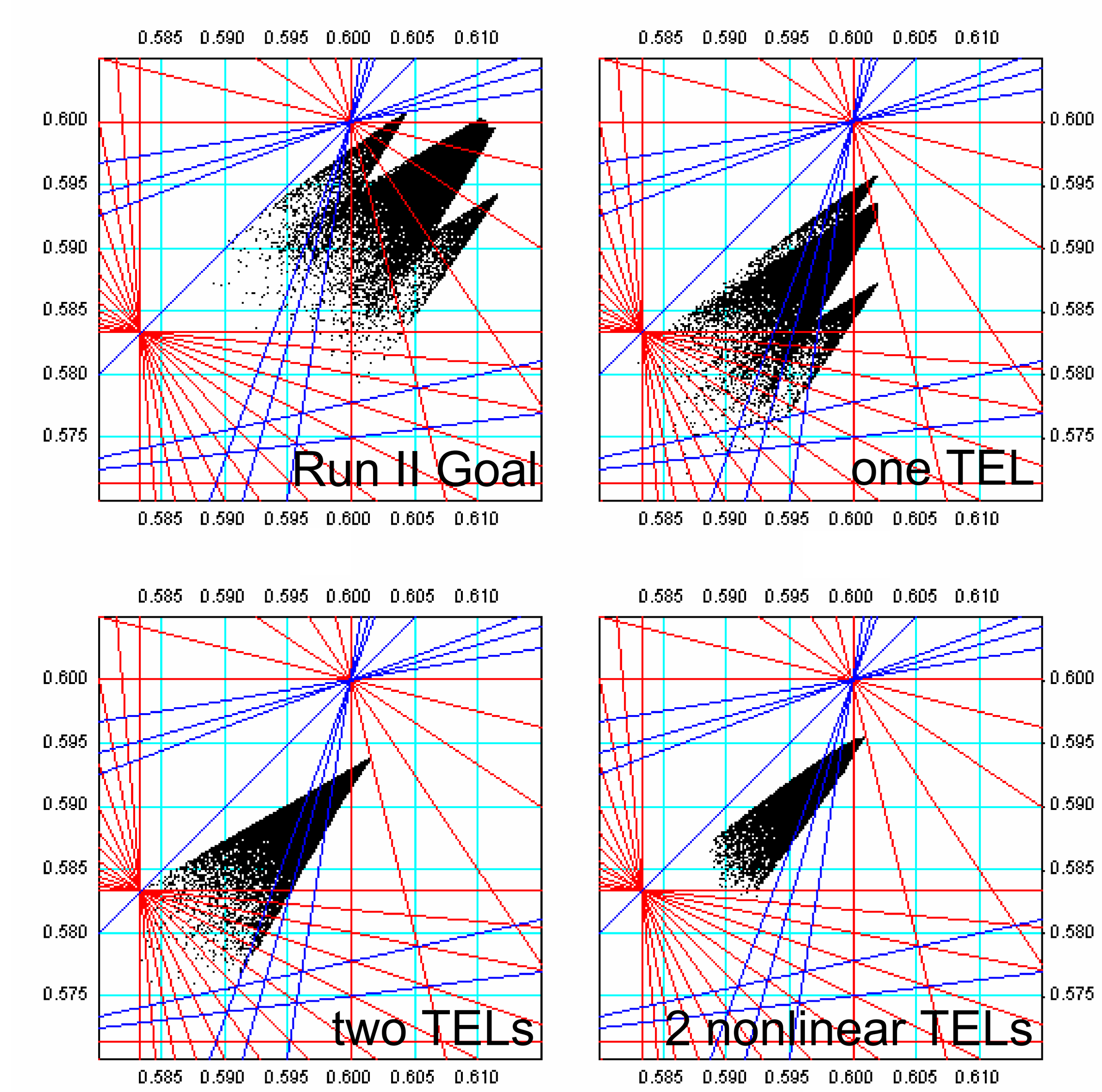
TEL one has been operated successfully to perform BBComp studies and became an operational device for abort gap cleaning.

TEL1 layout

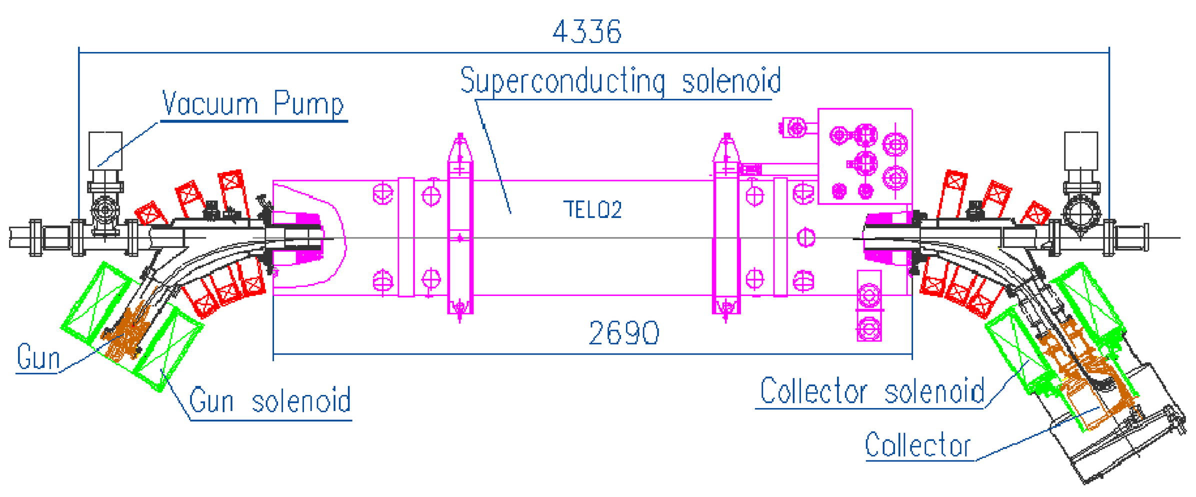


Calculations showed that a second TEL is needed in order to efficiently reduce tune spread in both planes

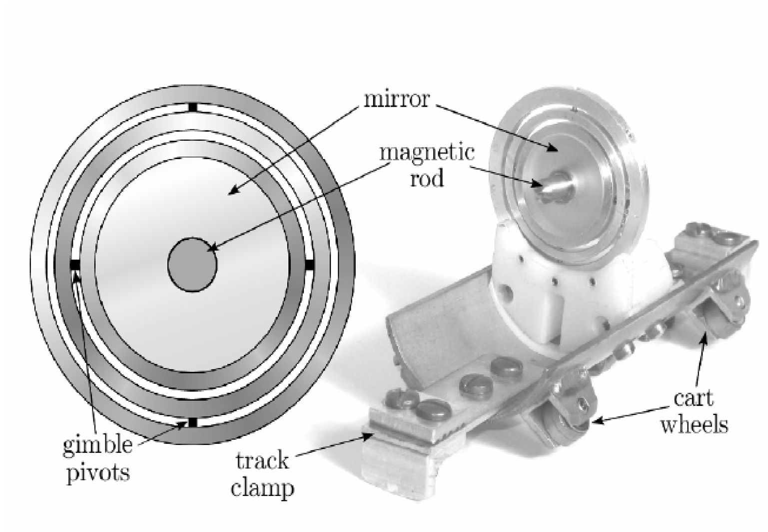
Calculated pbar tune spread



TEL2 layout

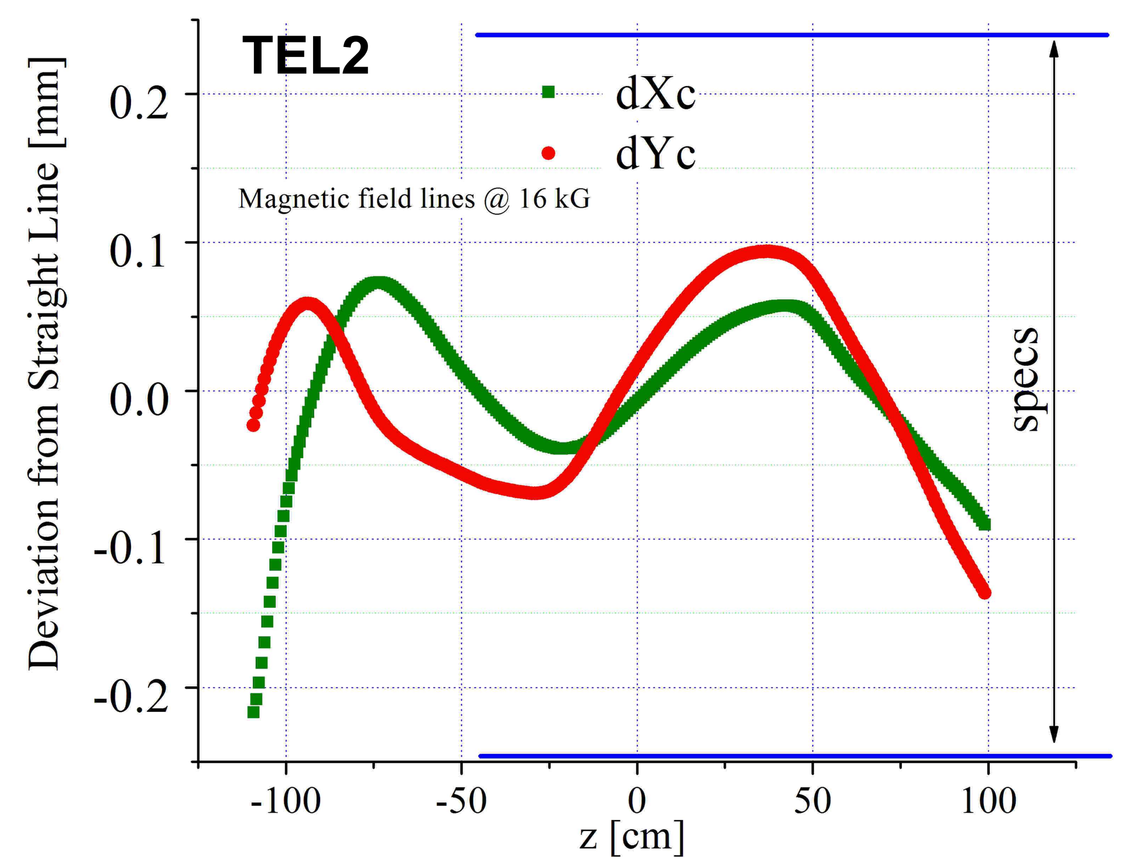


TEL2 has been tested prior to installation in the Tevatron. Magnetic field quality was measured using a hall probe and a laser based method. The second method utilizes a laser which is aligned along the solenoid axis. Its light is reflected by a magnetic mirror which is mounted on a cart dragged through the solenoid. The light is detected by means of a position sensitive detector. Since the mirror aligns itself perpendicular to magnetic field lines, the measured light spot position is a measure of magnetic line straightness. Measured straightness agrees with initial specification.



Mirror used to measure magnetic line straightness

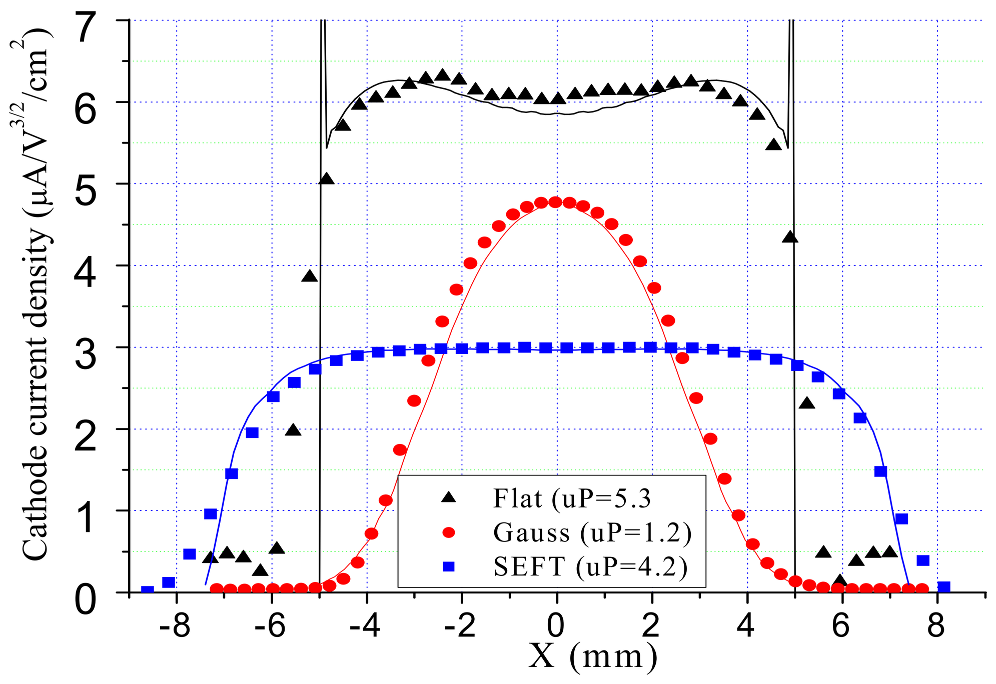
Straightness of magnetic lines in the main solenoid



Development of electron guns

TEL1 was initially equipped with a high perveance gun that features uniform (flat) transverse charge distribution. Beam studies using this gun showed tune shifts up to 0.009 accompanied by high losses due to edge effects. A “gaussian” gun was introduced in 2002 and allowed to greatly reduce losses. To make e-beam alignment less critical and to increase the perveance a new smooth-edge-flat-top (SEFT) gun was commissioned in 2005 showing a good compromise between perveance and electron beam profile for linear BBComp.

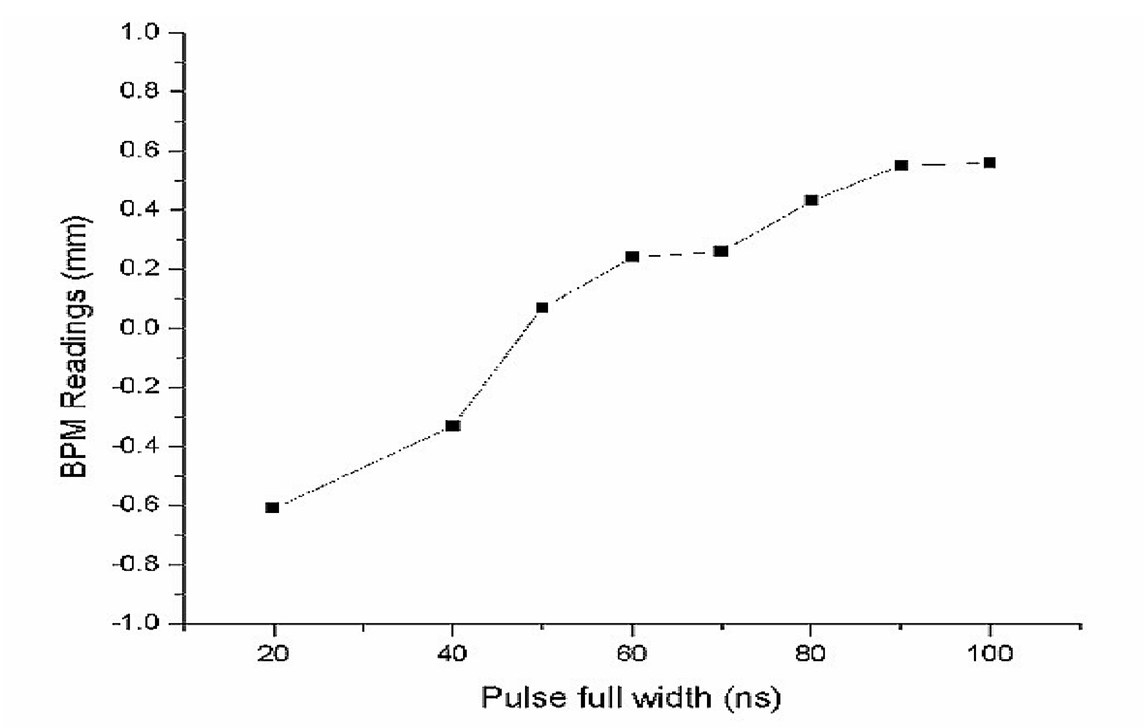
e-beam profiles, measured and calculated



Improvement of BPMs

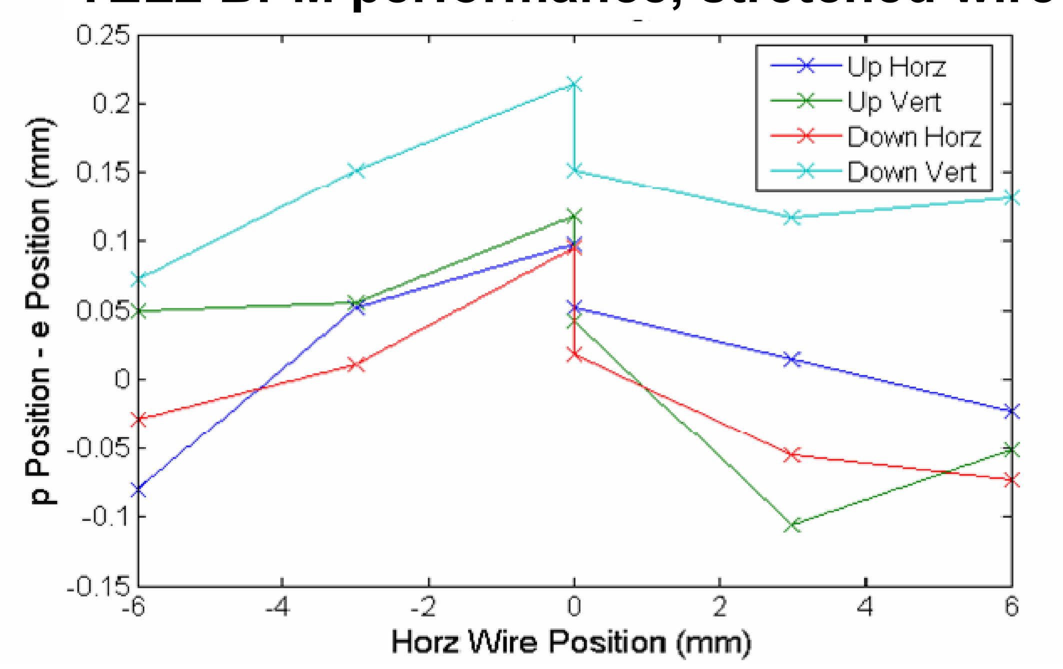
TEL1 BPMs (diagonally cut cylinders) are known to report different position depending on beam pulse width. The difference can be up to 1.2 mm.

TEL1: beam position vs pulse width



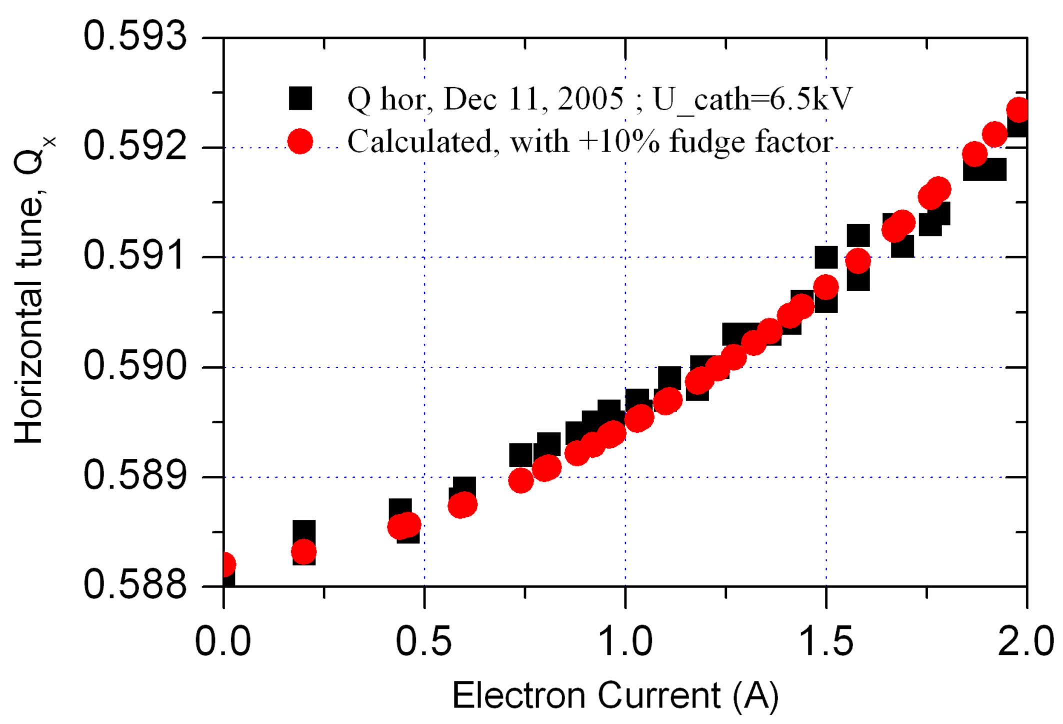
TEL2 BPM design utilizes four plate geometry with grounded electrodes between the plates to reduce crosstalk. They have been calibrated using a stretched wire and electron beam pulses of different width. The accuracy is better then 0.2 mm.

TEL2 BPM performance, stretched wire

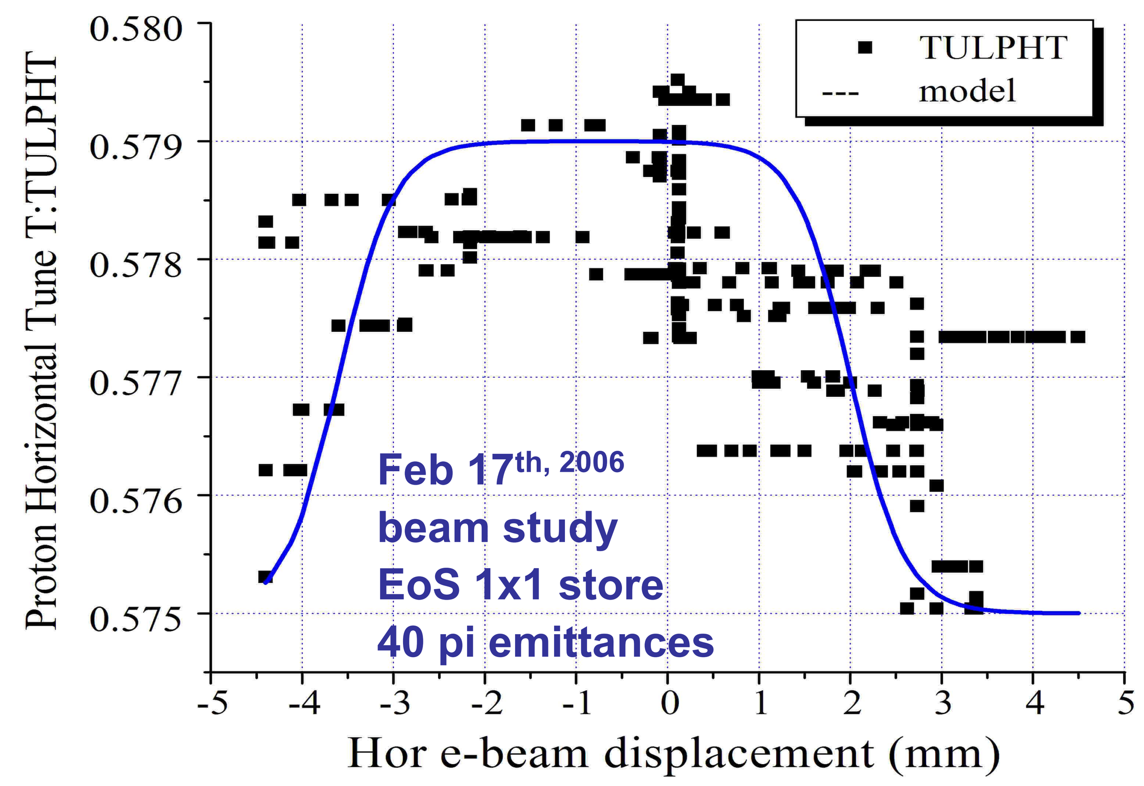


Measured tune shift and lifetime

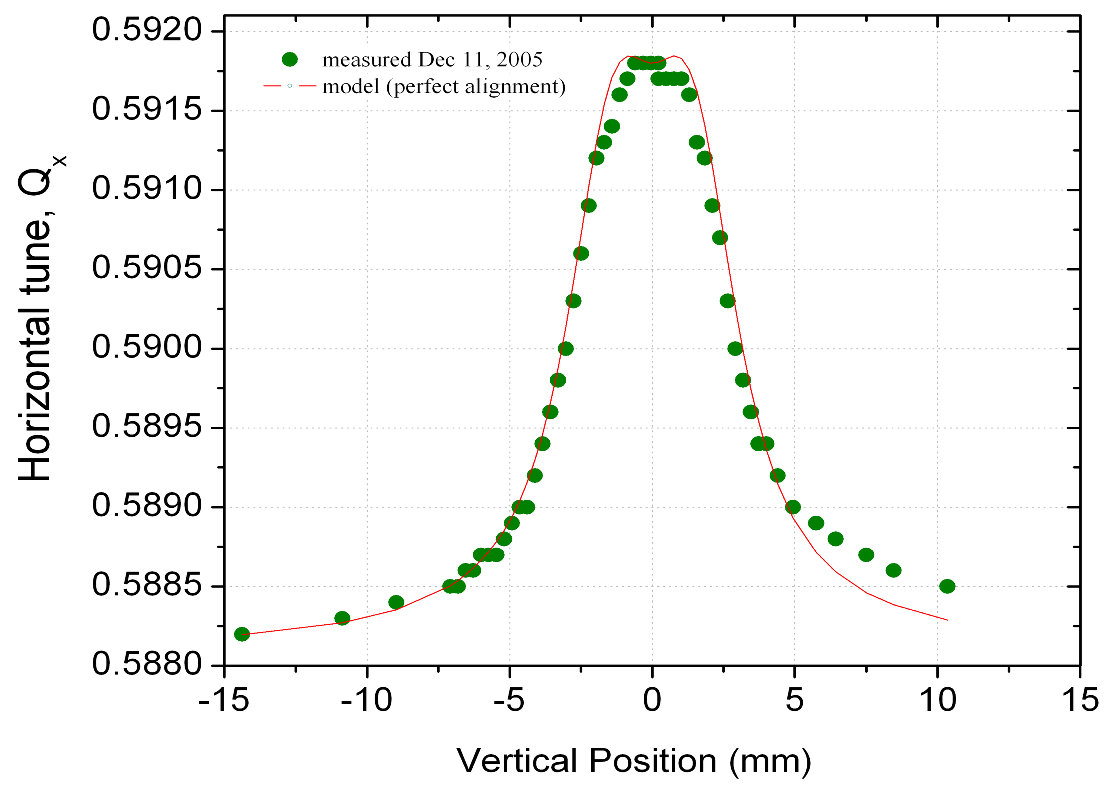
dQx vs e-current



dQx vs horizontal e-beam displacement



dQx vs vertical e-beam position



Using SEFT gun lifetimes of 700 hrs with dc e-beam and 340 hrs in pulsed regime have been observed. Presence of e-beam does not effect life time significantly. However, losses occur while tuning e-beam. Typically peak e-current was in the range 0.7-2 A.

Plans

- Assemble two more SEFT guns (in manufacturing)
- Commission TEL2 in the Tevatron
- Find an alternative way to clean the abort gap
- Use both TELs for Beam-Beam compensation
- Compensate many/all bunches simultaneously at low peak e-currents
- Improve e-beam stability/ripple to reduce losses
- Perform simulations of:
  - Liftime vs e-beam alignment
  - How does the bend shape effect BBComp
  - Lifetime vs dispersion

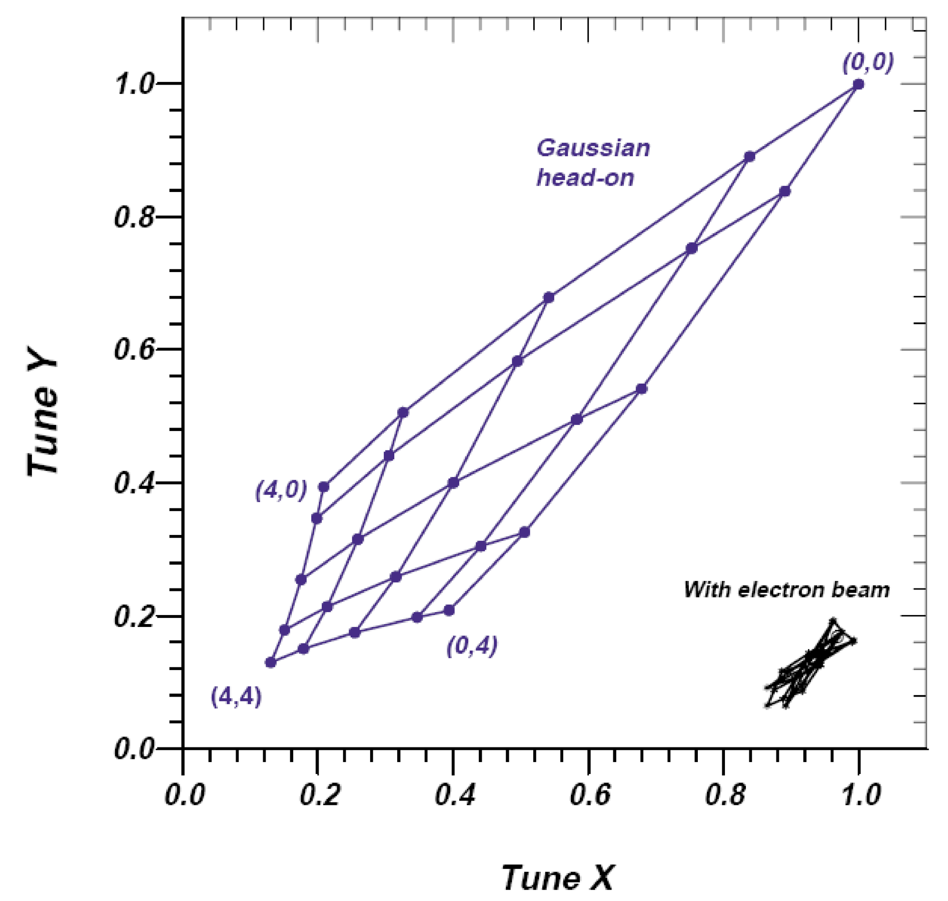
BBComp in LHC

After intensity upgrade in the LHC head on beam-beam compensation can become beneficial.

How does it work?

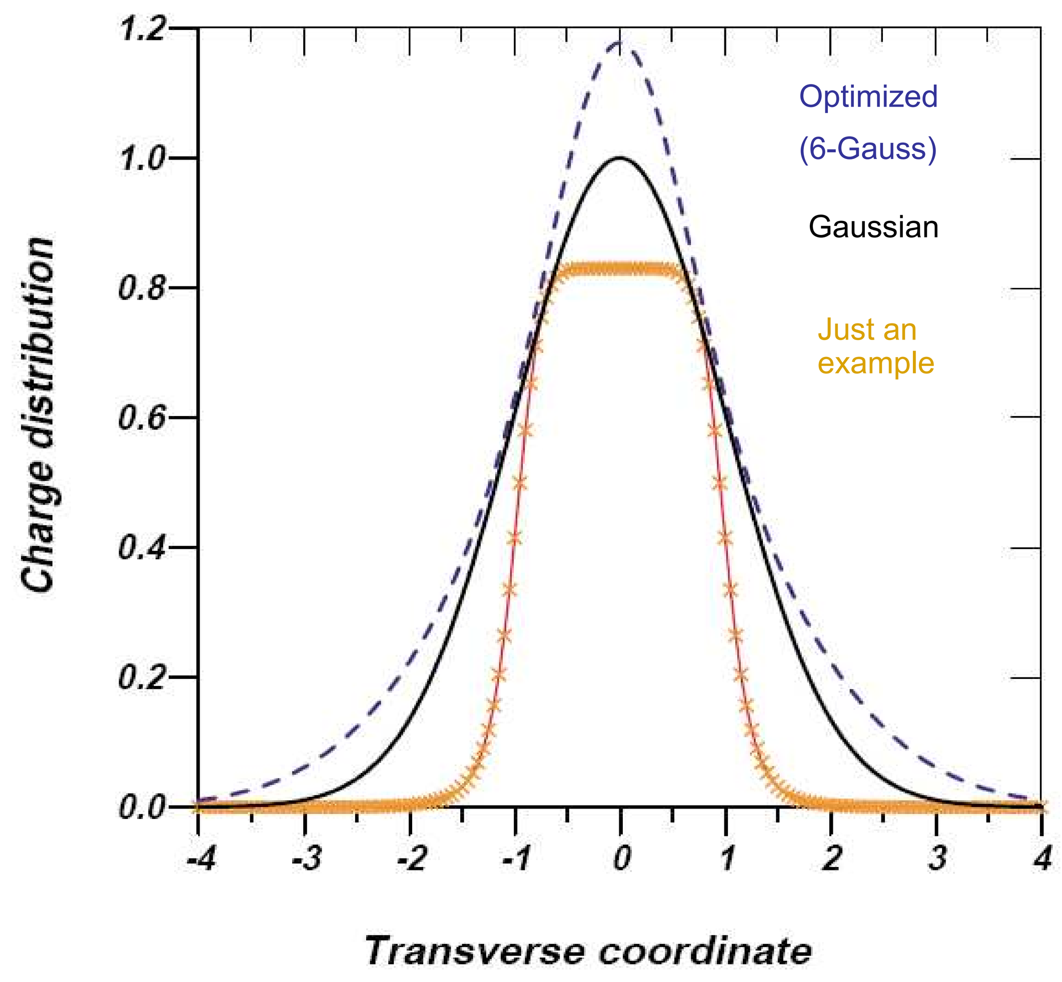
- Electrons compensate protons – that's good!
- DC beam → no HV pulsers,
- Need 2 lenses – one per beam at equal beta's
- Large beta is ~OK
- E-beam profile should be Gaussian (rms 0.3-0.5 mm) to match protons at IPs – can be done
- Need dQ_max~0.01 - achievable

Electron compression of head on footprint (calculated for pbars)



Tunes are given in units of head on beam-beam parameter. Numbers in parentheses show hor and vert betatron amplitudes in units of rms pbar beam size. The case with electrons is shifted for clarity.

For LHC $N_p=1.1^{11}$, $N_{ip}=4$, for 10kV electrons (ß=0.2) one needs $J_e=1.2$ A and 3 m long e-beam



Challenges of head-on beam beam compensation

- Total current is not a challenge
- Optimum beam profile is important
- Compression to 0.3-0.5 mm is doable, though not easy
- Keeping beam straight within 0.03-0.05 mm
- Beam-beam centering within 0.03-0.05 mm